PRACTICAL WIRELESS

circuit guide

2 Transistor Circuits

*presented with the June 1966 issue

THIS second booklet deals with the nature of circuits in which transistors are used. As far as possible, the circuits given here represent the 'solid-state' equivalents of the circuits given in the valve-circuit booklet (presented free in the May 1966 issue of *Practical Wireless*). This form of presentation will enable constructors and enthusiasts to glean some idea of what is required to transistorise a valve circuit of specific type.

The third, and final, booklet in this series, to be presented with the July, 1966 issue of *Practical Wireless*, will consider the servicing aspects of the various circuits dealt with in the first two booklets, and it will also tell how to set about getting the circuits working properly.

R.F. Amplifier

The first solid-state circuit, then, is the r.f. amplifier. This can be either untuned (called aperiodic) or tuned. The untuned and the tuned circuits are shown respectively in Figs. 1 and 2. In Fig. 1 the input circuit is fed direct to the base of the transistor and extracted from the collector, this being loaded with an r.f. choke. The choke has a high impedance to the range of frequencies handled, thereby causing a relatively high signal voltage to be present at the collector.

The amplification factor of this simple circuit is influenced by the signal gain of the transistor and by its cut-off frequency. Greater gain at higher frequencies will be obtained by the use of a transistor with a high signal (or a.c.) gain and a

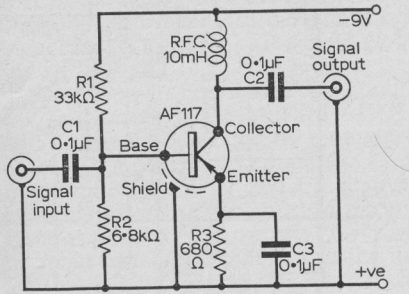

Fig. 1.

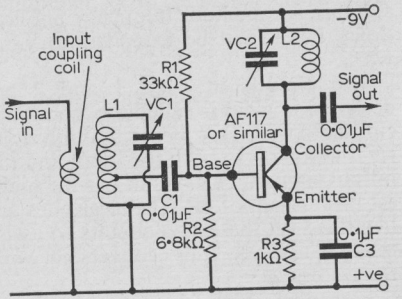

Fig. 2.

high cut-off frequency, assuming, of course, that the collector choke matches the frequency requirements. A choke of about 10mH and an AF117 transistor should give a signal voltage gain of around eight times over the l.w. and m.w. broadcast bands. The circuit, however, suffers the disadvantage of having no selectivity.

In applications where it is required to discriminate against other signals, the tuned r.f. amplifier of Fig. 2 is needed. This is tuned both at the base and the collector by L1/VC1 and L2/VC2 respectively. This sort of arrangement would be

suitable for medium frequency applications, but it can be extended to v.h.f. work.

The circuits in Figs. 1 and 2 are designed in what is called the 'common-emitter' mode. This means that the emitter is common to both the input and the output signals. This circuit has the highest power gain of all. The electrodes are identified on these two circuits to assist readers not yet fully conversant with transistors.

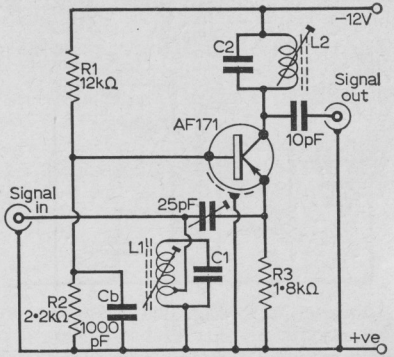

Fig. 3.

Improved high-frequency performance is often possible by the use of the so-called 'common-base' mode. This sort of circuit is shown in Fig. 3, which shows that the base is made common to both the input and output signals, capacitor Cb performing the function without disturbing the d.c. operating conditions of the transistor. Here the signal is applied to the *emitter* and extracted from the collector as before.

The emitter circuit (or the base circuit in Fig. 2) can be untuned, the signal then being applied through a coupling/isolating capacitor direct to the appropriate electrode. This may instigate a certain mismatch and impair the transfer-

ence of the signal from the source to the amplifier. The net result may be that the noise performance of the circuit is not as good as it could be with a tuned input circuit, matched at the input electrode by tapping down the input coil as shown in Fig. 3.

The circuit in Fig. 3 makes a good f.m. booster amplifier using a 100Mc/s transistor, such as the Mullard AF171 or equivalent type. Tuned circuits L1 and L2 should be wound on a quarter-inch former with dust-iron core adjustment. Six turns close-wound 26 s.w.g. enamelled-covered wire should tune over Band II with C1 and C2 approximately 25pF, depending on the stray capacitances and inductances of the amplifier design. Leads should be kept as short as possible, and the two tuned circuits should be screened from each other to avoid instability. The tap to the input on L1 should be $1\frac{1}{2}$ turns from the 'earthy' end of the coil.

Transistor Biasing

For a transistor to work as an amplifier its base needs to be biased in a similar way to the grid of a valve. However, whether the bias is negative or positive with respect to the emitter depends on the type of transistor used. There are two main types, the p-n-p type and the n-p-n type. In the circuits so far examined the p-n-p type is used. The type is identified by the emitter symbol arrow. With the arrow pointing towards the base it is p-n-p and n-p-n with it pointing away from the base.

P-N-P transistors require a negative base bias and a negative potential on the

collector, while n-p-n transistors require a positive base bias and a positive collector potential. In the circuits of Figs. 1, 2 and 3 resistors R1 and R2 set the base bias, which generally needs to be a fraction of a volt. These resistors form a potential-divider across the power supply, and their values are arranged so that only a small fraction of the supply voltage is tapped off. When the base is correctly biased, a small emitter-base current flows and this instigates a flow of collector current and, within limits, the greater the former, the greater the latter. When the former is superimposed with signal current, the collector current is similarly superimposed. This is the basic function of a transistor, amplification occurring because the small base current in a low impedance circuit produces a larger collector current in a high impedance circuit. The reason why the impedance of the collector circuit is higher than that of the base circuit is because the emitter-base junction is biased for forward conduction while the collector-base junction is biased for reverse conduction. For further information on the theory of transistors, the reader is advised to consult the literature.

It will also be seen that all the circuits so far contain a resistor, R3, in the emitter circuit. This contributes a little to the base biasing, but in Figs. 1 and 2 its main purpose is to stabilise the d.c. conditions of the transistor. When a transistor warms up, leakage current flows in the collector circuit. This produces more heat which in turn produces more leakage current. Unless something is done to hold back this effect the transistor could be destroyed. The effect is called 'thermal runaway' and R3 helps to solve the problem.

It works like this. Should the collector leakage current increase, more current

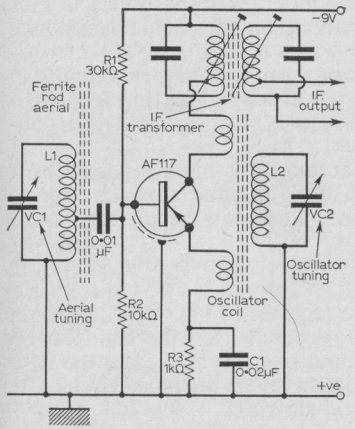

Fig. 4.

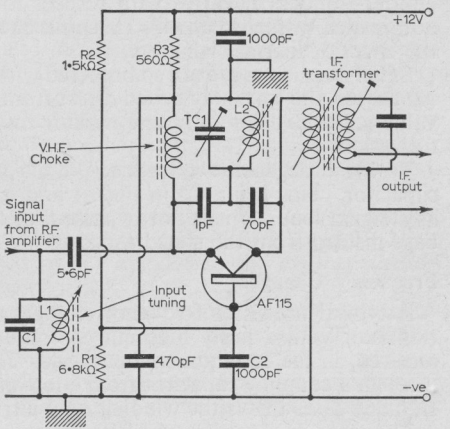

Fig. 5.

would flow in R3. An increased volts drop would thus develop across the transistor, the effect of which would make the emitter go more negative with respect to the base. This is the same as the base going more positive with respect to the

emitter—or less negative with respect to the emitter. The base bias is thus automatically 'turned down'. This pulls back the collector current and neutralises the effect of thermal runaway.

Small transistors are not so bothered with the problem and R3 may be omitted. Moreover, the base may be fed direct from the power supply line through a high value resistor, using only one resistor instead of two in potential-divider configuration.

To avoid degenerative feedback, the signal across R3 is often bypassed by a capacitor. This being C3 in Figs. 1 and 2. In Fig. 3 the emitter resistor serves as a signal load, so it is not bypassed, of course. Cb in this circuit 'earths' the base instead from the signal aspect.

Frequency Changer

A typical transistor frequency changer stage is given in Fig. 4. This uses a transistor with a fairly high cut-off frequency, depending on the bands to be received, in the common-emitter mode. The input signal is applied to the base through a coupling capacitor from a low impedance tap on the tuned circuit L1. In many cases this is the winding on a ferrite rod aerial.

The stage is caused to oscillate at the required local oscillator frequency by coupling windings on the oscillator coil between the collector and emitter, tuning being by a tightly-coupled winding across which the oscillator section of the tuning gang is connected.

The tuned incoming frequency thus beats with the oscillator frequency and

produces a new signal at the intermediate-frequency. This is developed across the windings of the i.f. transformer, and then fed out to the i.f. amplifier stage from a tap on the secondary winding. The primary winding is also coupled to the collector circuit of the frequency changer transistor via a suitable impedance tap. The idea of these taps is to avoid the tuned circuits being loaded excessively by the relatively low transistor impedances and to secure the best power coupling bearing in mind that a transistor is essentially current-operated as distinct from a valve which is voltage-operated.

The two tuned circuits are ganged in such a manner that over the entire tuning range there is always the i.f. difference between VC1/L1 and VC2/L2. It will be seen that the base is biased by R1 and R3 in the manner already described. There is also the emitter resistor R3.

C1 across R3 is rather important since it controls to amplitude of the oscillations to some degree. If this component is open-circuit the stage will probably fail to oscillate, while if its value is too large the amplitude of oscillations will be excessive and the stage may block. The frequency changing action would also be impaired. This latter may also happen with insufficient oscillation amplitude.

Sometimes the value of C1 needs to be modified if a more up-to-date transistor is used as a frequency changer in a set of early design. As in valve circuits, the i.f. is 470kc/s for a.m. and 10·7Mc/s for f.m.

A practical circuit would feature switched coils for wavechanging, trimming and padding preset capacitors to allow the circuits to be adjusted for the best

tracking over the whole of the various wavebands. In simple l.w./m.w. receivers, the oscillator frequency is sometimes reduced for l.w. working by the wave-change switch putting a l.w. capacitor in parallel with the oscillator tuned circuit. This avoids switching in the oscillator coil proper.

Fig. 5 gives circuit details of a v.h.f. frequency changer for the f.m. band, Band II. As this may be a part of a valve receiver (i.e., valves in the audio sections), it may be desirable to arrange the circuit to suit a positive power supply line—as distinct from the negative line of the previous circuits. Supply may then be picked up from a Zener diode across the ordinary valve h.t. supply or from across a cathode resistor in a power valve circuit. The circuit shown is arranged in this manner.

We still have the bias resistors R1 and R2 and the emitter resistor R3. The stage is arranged in the common-base mode, the base being earthed to signal through C2. The incoming signal, usually from an r.f. amplifier, is applied to the emitter through the isolating coupling capacitor. Thus, C1/L1 tunes the incoming signals, but here L1 is the variable element, instead of C1. This is called 'permeability tuning', a core mechanically coupled to the tuning mechanism being drawn in and out of the coil. The v.h.f. choke in series with the emitter resistor R3 'holds off' the input signal.

The oscillator is also permeability tuned, this being by TC1/L2, and the stage is caused to oscillate by the coupling between collector and emitter through the 1pF and 70pF capacitors. The i.f. signal (10·7Mc/s) is developed across the i.f. transformer and fed out to the first i.f. amplifier stage. In practice, C1/L1 would

probably be the collector tuned circuit of the r.f. amplifier. This circuit is fairly easy to get going, but care should be taken over its layout to avoid unwanted couplings and instability.

Oscillators

We have already seen two oscillators in the frequency changer circuits. These are called 'tuned oscillators' for obvious reasons. Tuned oscillators generally provide a sine-wave output signal, and the chief considerations are the same as those for valve circuits, explained in the first booklet of this series. Oscillation takes place when (i) the phase of the fed-back signal coincides with the phase of the output signal whence it is derived and (ii) when the loop or feedback gain is greater than unity. These conditions are not difficult to attain and, unfortunately, sometimes occur when oscillation is not required. In amplifiers, for instance, the feedback then being caused by poor screening, poor decoupling or unwanted coupling between the output and input elements of the circuit.

A simple tuned oscillator circuit is given in Fig. 6. Here the coupling is back from the collector to the base via the transformer, the collector winding of which is tuned by C1.

This is based on a Mullard design and for audio applications, the secondary of the transformer can be in the order of 5mH, tuned by 0·05μF. This will produce a signal of about 10,000c/s with the component values given. The output power will be about 20mW.

This is a very useful little circuit which always works and which can be tuned

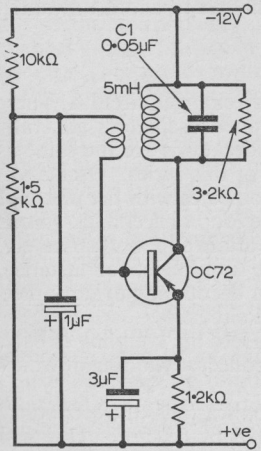

Fig. 6.

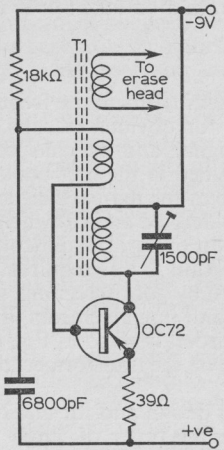

Fig. 7.

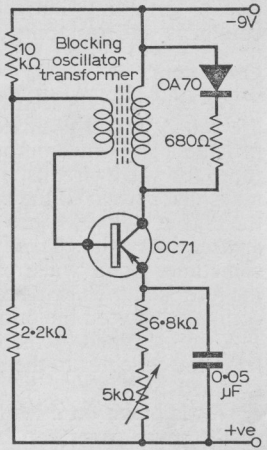

Fig. 8.

either by altering the collector inductance or the parallel capacitance. To increase the frequency the inductance or the capacitance should be reduced.

For higher frequency applications, ordinary r.f. tuned circuits (with a coupling winding) can be employed, but the transistor must be capable of (a) working at the required frequency and (b) delivering the required power at the required frequency. A turns ratio of about 40-to-1 (the fewer turns in the base circuit) is suitable for many applications.

For low frequency work, an iron-cored transformer is suitable. If the frequency is not too important, an ordinary inter-stage coupling transformer can be used.

The value of the base and emitter capacitors should be selected to suit the required oscillator frequency. These are shown as electrolytics in Fig. 6, but could be lower value components for higher frequency work.

A slightly different arrangement is shown in Fig. 7. Here transformer T1 provides not only the collector-to-base coupling but it also features an extra winding across which the oscillatory signal is developed. The base potential-divider network is replaced by a single resistor from base to supply negative and only a small value unbypassed resistor is used in the emitter circuit.

This kind of oscillator is sometimes adopted for tape erase and recording bias in tape recorders. The collector may be tapped a little way *down* from the top of the tuned winding and in some cases a trimmer capacitor may be included in parallel with the feed-out winding to tune the erase head coupling to maximum power.

Blocking Oscillator

While the 'blocking oscillator'—often used in television timebases—is not really a tuned oscillator and does not provide a sine-wave output, it does nevertheless use a transformer coupling to provide positive feedback. There are two versions, one which can be 'triggered' by an input pulse, the feedback then being applied to the emitter (in some circuits) instead of to the base, while the other is a so-called 'free-running' circuit since it sustains oscillation without triggering pulses.

The free-running circuit in basic form is shown in Fig. 8. When the circuit is first switched on feedback occurs between the collector and base circuit, via the blocking oscillator transformer and the transistor swings on to the first half-cycle of oscillation. This causes a sharp increase in emitter current which charges the emitter capacitor, making the emitter negative relative to the base that the transistor cuts-off and the oscillation is immediately muted. The stage thus remains in that condition until the capacitor discharges through the emitter resistors to an extent that permits another burst of oscillation. The same thing then happens again. In other words, the oscillation is blocked for a period of the time-constant of the emitter circuit.

The frequency of the resulting 'pulsed' output is controllable by varying the time-constant, and the variable resistor in the emitter circuit facilitates this. The diode and resistor damp the pulses at the collector.

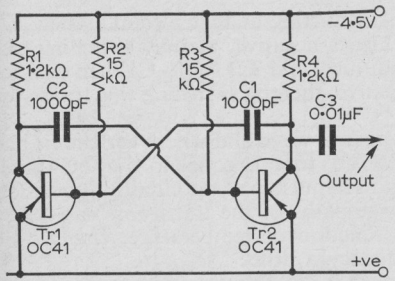

Fig. 9.

In the valve circuit booklet we saw that it is possible to produce the sine-wave signals without tuned circuit by the use of a 'phase shift' resistor-capacitor network in the feedback loop. Similar circuits are possible using transistors and a series of r.c. networks—in so-called 'ladder' formation are established between the collector and base circuits. The circuit oscillates at the frequency when the phase is correct, as for any oscillator, determined by the values of the r.c. elements.

Multivibrators

Again, transistors lend themselves admirably for use in multivibrator circuits. A workable circuit is given in Fig. 9. Like the valve circuit, the two transistors are cross-connected from the collector of the second to the base of the first and from the collector of the first to the base of the second. This produces the feedback effect necessary for sustained action.

When the circuit is first switched on one or other of the transistors switches 'on' and the other switches 'off'. Let us suppose that Tr1 in Fig. 9 is 'on' or

conducting and that Tr2 is 'off' or non-conducting at that instant. Then, C2 charges through R3 and the base of Tr2 goes negative, thereby switching this transistor 'on' (from its original 'off' condition), and Tr1 'off'. C1 then charges through R2 and the base of Tr1 goes negative, thereby switching this transistor 'on' and Tr2 'off'. So the cycle repeats.

The output signal is of the nature of a square-wave and where the circuit has balanced transistors and components, the 'on' time is equal to the 'off' time. That is, when C1.R2=C2.R3. The repetition frequency of the circuit is governed by these time-constants, though the leakage paths of the transistors can affect the frequency, and as the leakage is a function of temperature, changes of transistor temperature will alter the frequency a little.

The component values in Fig. 9 provide for a frequency in the order of 50kc/s. The output is taken from the collector of Tr2 (or Tr1), via a coupling capacitor.

The circuit can be arranged so that an input pulse changes the conduction of the transistors, but immediately afterwards the circuit regeneration restores the original condition. This is called a flip-flop circuit. Here one half of the re-generation network is effectively destroyed and a triggering pulse is applied to the base of one transistor to secure the 'flip-flop' action. This is sometimes called a 'monostable' circuit, since it is stable only on one cycle as it were.

A 'bistable' circuit is a rearrangement of the multivibrator whereby a pulse is necessary to switch, say, Tr1 'on' and Tr2 'off', while a second pulse is necessary to reverse the conditions; that is, to switch Tr1 'off' and Tr2 'on' again.

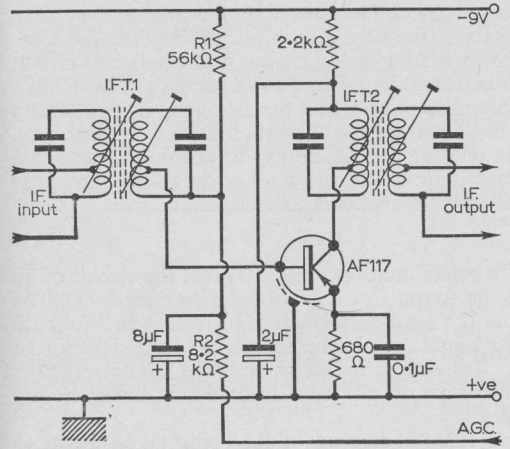

Fig. 10.

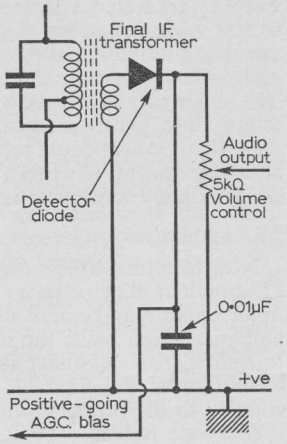

Fig. 11.

It is, of course, impossible to explore these variations of the multivibrator, but they are well covered in current semiconductor circuit literature. They have a host of applications ranging from frequency multiplication (with the free-running multivibrator) to control switching, using a relay in the collector circuit and pulses to operate the relay and thereby control some secondary switching. The pulses can be created by a press-button or from the change in light intensity falling on a photo-conductive resistor (or heat on a thermistor). In this way, then, light or heat could result in relay action which may be geared to work, say, an alarm system, to open a garage door or operate a set of curtains. The possibilities are enormous. Similar circuits are used in computers.

I.F. Amplifiers

Now to return to less exotic 'wireless' matters. Fig. 10 gives the circuit of an i.f. amplifier stage such as may be found in a typical transistor receiver. The input signal may be derived from the frequency changer or from a previous i.f. amplifier stage, while the output signal may be taken direct to the detector or to a further i.f. amplifier stage. If the signal is taken direct to the detector the secondary of the final i.f. transformer is not usually tuned, it being closely coupled to the primary winding.

The base is biased by R1 and R2, but instead of R2 being taken direct to the supply positive line it is returned to the a.g.c. circuit. Now, when the received signal is strong the a.g.c. system produces a positive potential, and this counters the negative base bias of the transistor, thereby reducing its gain. The a.g.c.

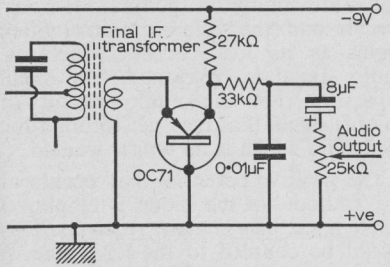

Fig. 12.

action is sometimes assisted by a damping diode connected in series with a resistor to the collector circuit of the frequency changer transistor. This also prevents instability when the tendency is for the collector impedance to rise with strong signals.

The 8μF capacitor from the junction of R1/R2 to the positive line decouples the a.g.c. circuit and puts the 'dead' side of the secondary of the first i.f. transformer to 'chassis'.

The i.f. amplifier in a.m./f.m. receivers is very similar and, as with valve circuits, adopts two i.f. transformers with their primary and secondary windings connected in series, one tuned to the f.m. i.f. (that nearest to the signal source—such as the collector or base) and the other tuned to the a.m. i.f. Full circuit information on this technique is contained in the valve circuit booklet.

Detectors

The most common solid-state detector is the half-wave rectifier circuit employing a germanium diode, as shown in Fig. 11. This is coupled from an

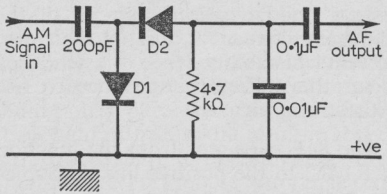

Fig. 13.

untuned winding on the final i.f. transformer and the volume control often serves as its load, across which the audio signal is developed. The small capacitor rids the audio circuit of any i.f. signal that may get through the diode and which is no longer wanted.

The positive potential that occurs at the 'cathode' of the diode is employed as the a.g.c. bias in many receivers. This would be coupled to the a.g.c. line of the circuit in Fig. 10. Thus, the 'cathode' of the detector diode is in series with R2 in Fig. 10, being the bottom arm of the i.f. amplifier base potential-divider, the upper arm being R1. This means that the 'cathode' of the diode has a little negative bias applied to it, which is desirable in that it gives a little forward conduction and enhances the detection efficiency, particularly at low signal levels.

An interesting transistor detector is shown in Fig. 12. Here the emitter-base junction of the transistor acts, as it were, as the rectifier, and the resulting demodulated signal in this junction produces a corresponding amplified signal across the 27kΩ load resistor in the collector circuit, from whence the audio is fed to the volume control.

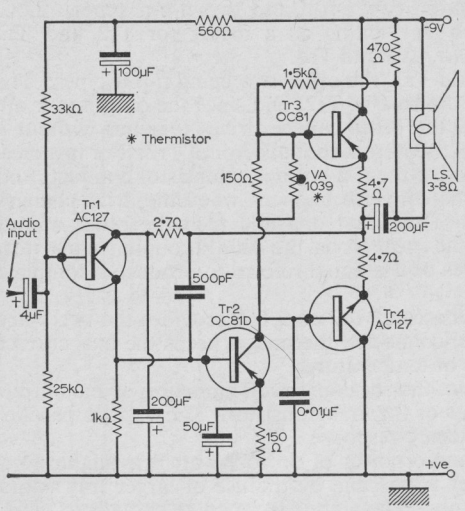

Fig. 14.

Small receivers sometimes employ a pair of diodes in a voltage-doubling rectifier system, as shown in Fig. 13. Here the a.m. signal is applied through a coupling capacitor and the audio is finally developed across the 47kΩ load resistor.

Detectors for f.m. can use either thermionic diodes or semiconductor diodes. The valve circuit booklet contains full details of such circuits, the thermionic diodes in which can be substituted for semiconductor diodes without loss in performance.

Audio Stages

The trend is now to employ p-n-p and n-p-n transistors in so-called stabilised 'complementary mode' transformer-less push-pull. A typical circuit given in Fig. 14.

This uses a total of four transistors, two p-n-p and two n-p-n types. D.C. coupling is used throughout with Tr1 acting as a driver for Tr2 and Tr2 acting as a driver for the output pair, Tr3 and Tr4.

The p-n-p transistors are Tr2 and Tr3, the other two being n-p-n types. The collector of Tr1 is d.c. coupled to the base of Tr2, and since the output pair are p-n-p/n-p-n complementary types, the bases can be drives together without a transformer or phase inverter stage direct from the collector of Tr2. For instance, when the drive signal is positive-going, the n-p-n output transistor conducts and the p-n-p partner switches off. The converse happens when the drive changes cycle—changes to negative-going. Thus, first one and then the other output transistor feeds signal power into the speaker via the 200μF coupling capacitor, and the action is that the half cycles of the signal reform to produce a complete signal across the speaker.

The 150Ω resistor between the bases of Tr3 and Tr4 provides the necessary biasing balance, while the parallel-connected thermistor keeps the bias correct (for class B working) over a range of temperatures.

Negative feedback is applied from the speaker circuit (junction of the output pair emitter resistors) to the emitter of the first transistor. The various parallel capacitors correct phase and frequency response.

With the transistors shown an audio power of up to $\frac{1}{4}$-watt is available to a 3 to 8-ohm speaker. Larger power is possible by the use of larger transistors and a more substantial power supply. The circuit is sensitive enough to work from the signal present at the output of an average diode detector circuit.

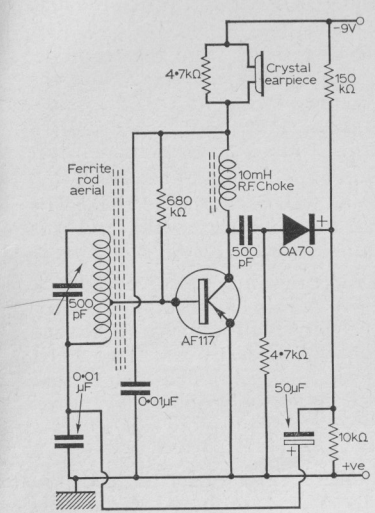

Fig. 15.

Small reflex receiver circuit

An interesting circuit of a 'reflex' receiver is given in Fig. 15. This uses one transistor only and a germanium diode detector, the output being sufficient to operate a small crystal earpiece at low-level. No outside aerial is needed as the sole tuned circuit is wound on a length of ferrite rod, which then acts itself as the aerial.

The signal picked up by the aerial is fed, from a suitable low impedance tapping, to the base of the transistor, this being biased by a single high-value resistor to the supply negative line. Owing to the very small current involved, no emitter resistor is used.

The transistor thus amplifies the aerial signal and develops it across the r.f. choke in the collector circuit. The 'cold' side of this is held at low signal potential by the 0·01μF capacitor to the battery positive line, and the r.f. signal at the collector is coupled to the diode detector through 500pF capacitor.

The diode's d.c. circuit is completed through the 4·7kΩ resistor, which the load consists of the 10kΩ resistor to the diode 'cathode'.

Detector efficiency is improved by the 150kΩ resistor from the 'cathode' putting a little forward current in the diode from supply negative line. Now, the audio signal developed across the 10kΩ load is coupled through the 50μF electrolytic capacitor to the base of the transistor, via the aerial winding. The 0·01μF gives a return for the aerial signal circuit and at the same time acts as a detector filter.

The transistor thus carries the audio signal as well as the r.f. signal. The audio is developed across the 4·7kΩ resistor in the collector circuit, and it is this which works the earpiece connected in parallel with the load.

It is possible to improve the sensitivity by introducing a little positive feedback to the top of the aerial winding from the collector. A very small value capacitor —probably less than 1pF is all that is required here. If too much capacitance is used the transistor will oscillate and reception will be destroyed. Two short lengths of p.v.c. covered wire connected to the points mentioned and twisted together can be used to control the feedback. Usually, only one or two turns are necessary.

For m.w. use, the aerial winding can consist of about 60 turns of No. 26 s.w.g. enamel covered wire on a rod of about $\frac{3}{8}$in. diameter. The longer the rod, the better the pickup of signal by the aerial. The tap to the base should be made at about 10 turns from the bottom of the coil.